Helmholtz-Institut Jena

Nanometer optical coherence tomography using broadband extreme ultra violet light
XCT

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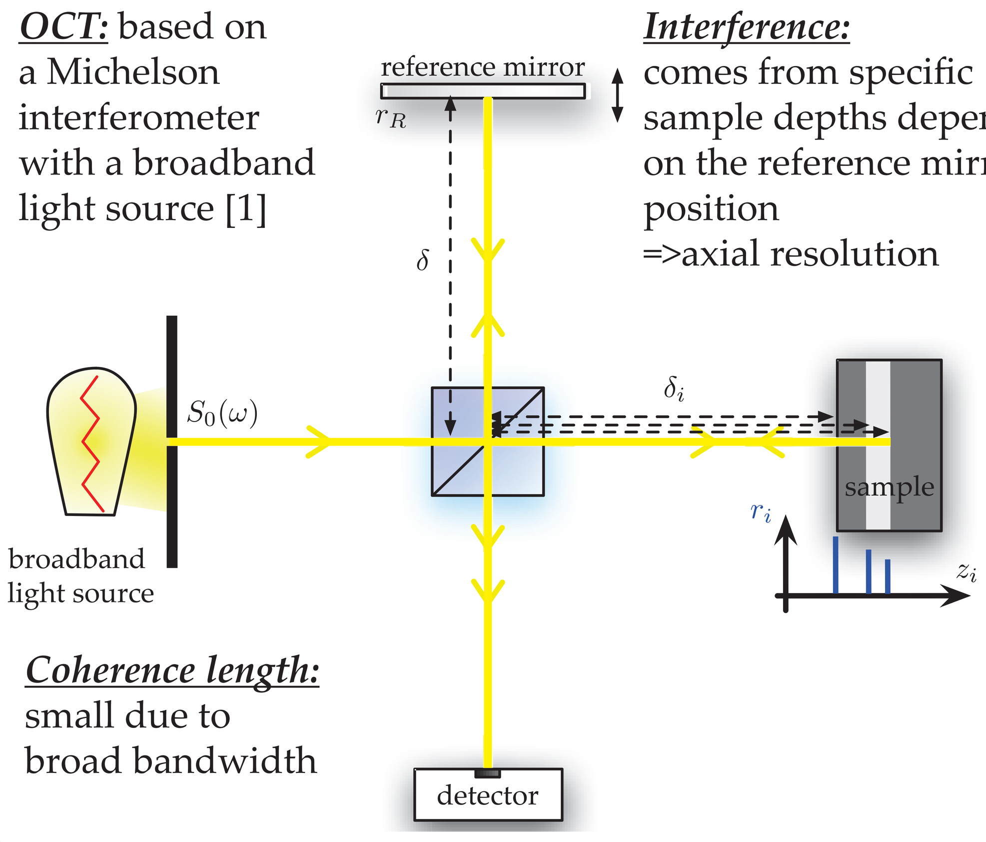
Introduction: Optical Coherence Tomography

OCT - established technique with broadband IR radiation

OCT: based on a Michelson interferometer with a broadband light source [1]

Interference: comes from specific sample depths dependant on the reference mirror position =>axial resolution



Coherence length: small due to broad bandwidth

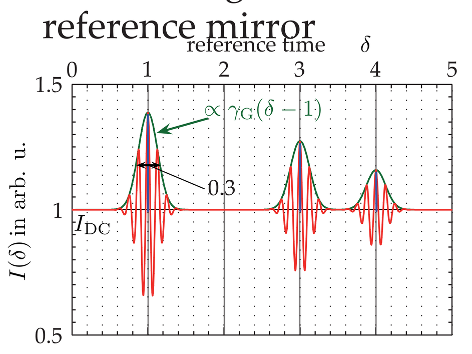
Different OCT methods

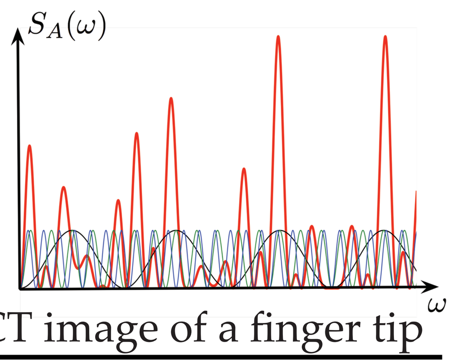
Time-domain OCT: measuring intensity and moving reference mirror

Wiener-Khinchin

$\mathrm{FT}\,[S_A(\omega)] \propto \gamma(\delta)$

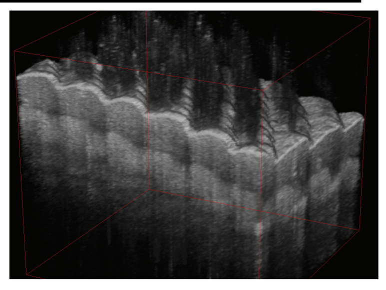
Fourier-domain OCT: measuring the reflected spectrum





Medical OCT device

OCT image of a finger tip



Resolution: few micrometers

Penetration depth: few millimeters [2]

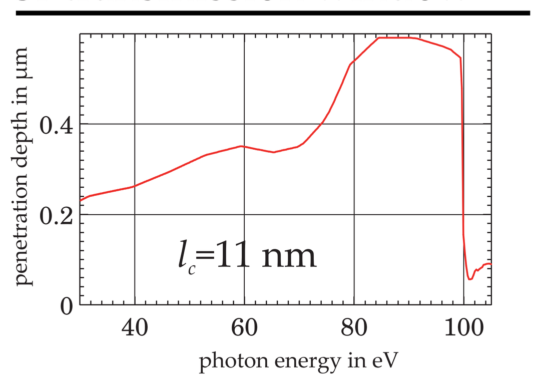
XUV Coherence Tomography

Axial resolution depends on coherence length only

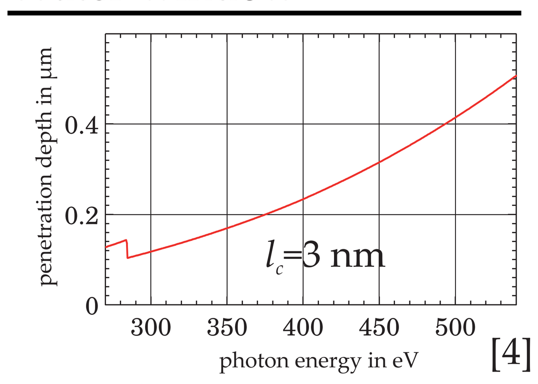
$$l_c = \frac{2\ln 2}{\pi}\,\frac{\lambda_0^2}{\Delta\lambda_{\mathrm{FWHM}}}$$

- short wavelengths and broad spectrum lead to high resolution => with XUV-radiation: Nanometer resolution
- strong absorption in the XUV => spectral transmission windows of the sample materials limit the bandwidth and the resolution

Si-transmission window



Water-window



[4]

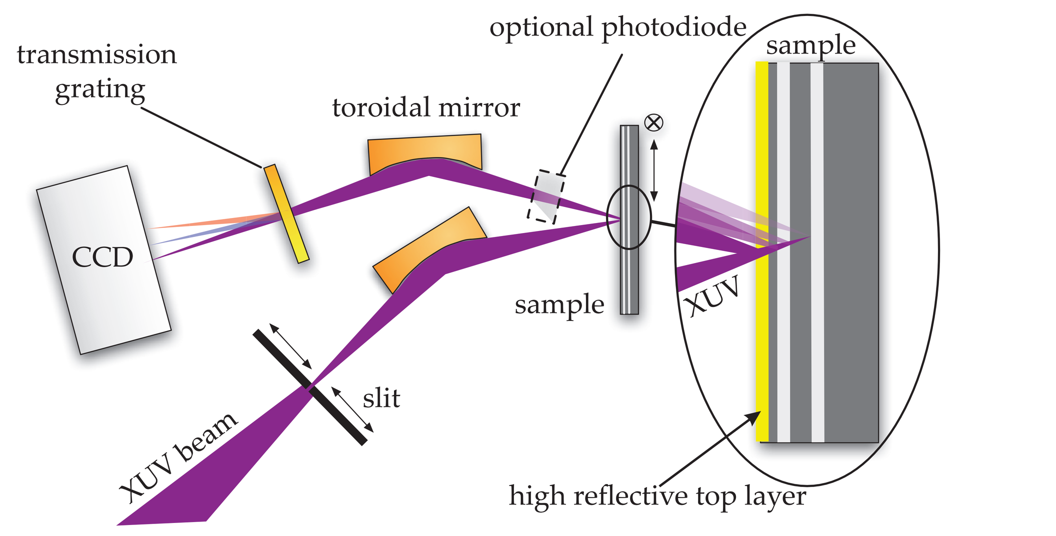
- first experiments were performed at synchrotron radiation sources

DESY BESSY

Experimental setup

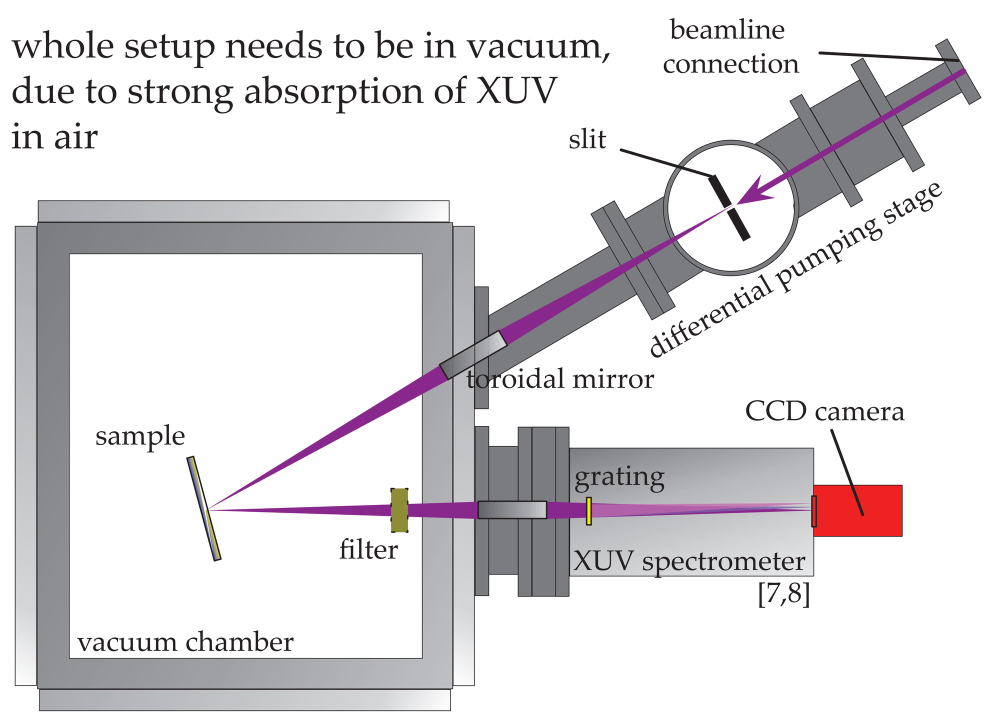
Schematic sketch of the XCT setup

- broadband beam splitter aren't available in the XUV regime [5] => Michelson-based setup not suitable [4,6]
- instead, a Common-Path setup was used
- a high reflective thin top layer replaces the reference mirror [3]



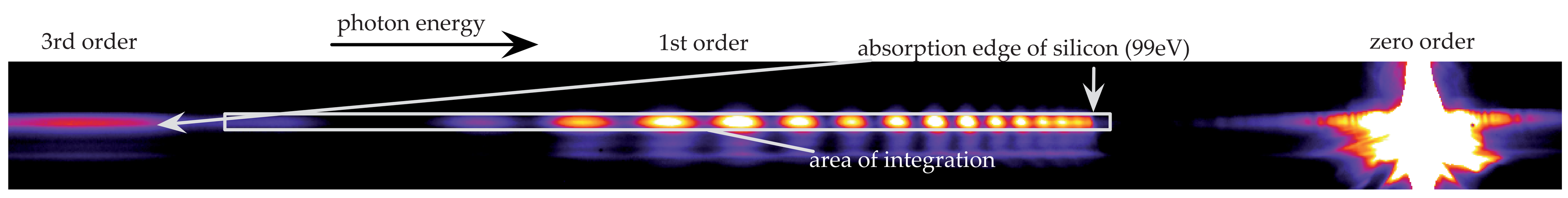
Optics, optical path & vacuum chamber

- whole setup needs to be in vacuum, due to strong absorption of XUV in air

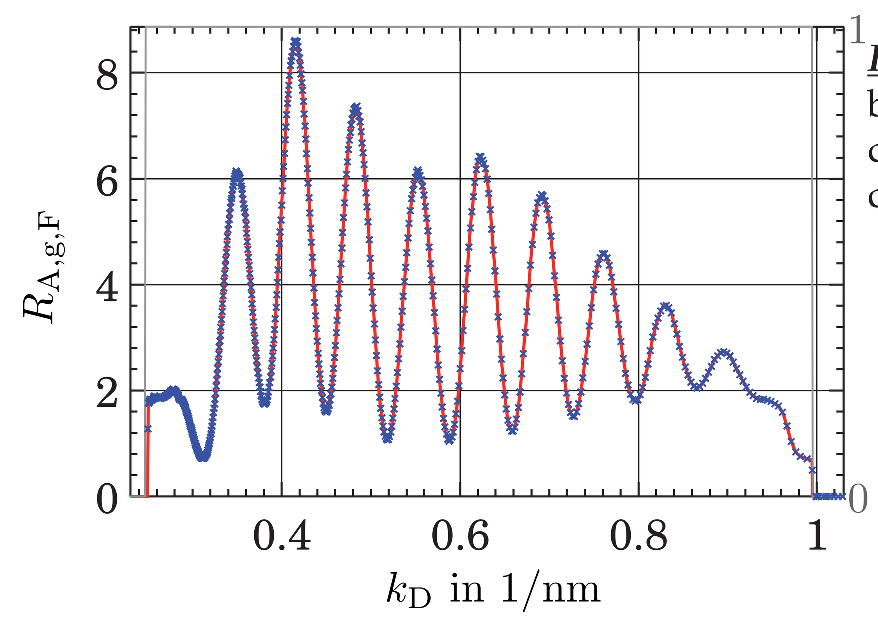


Experimental results with synchrotron sources

Raw data image: XUV spectrum of a silicon and gold layer system



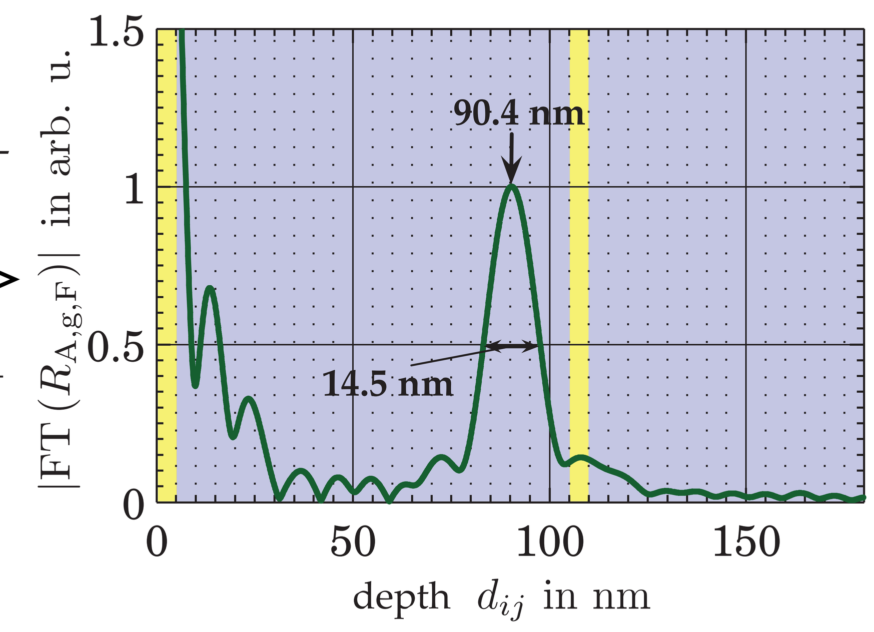
Si- & Au-layers in the Si-transmission window



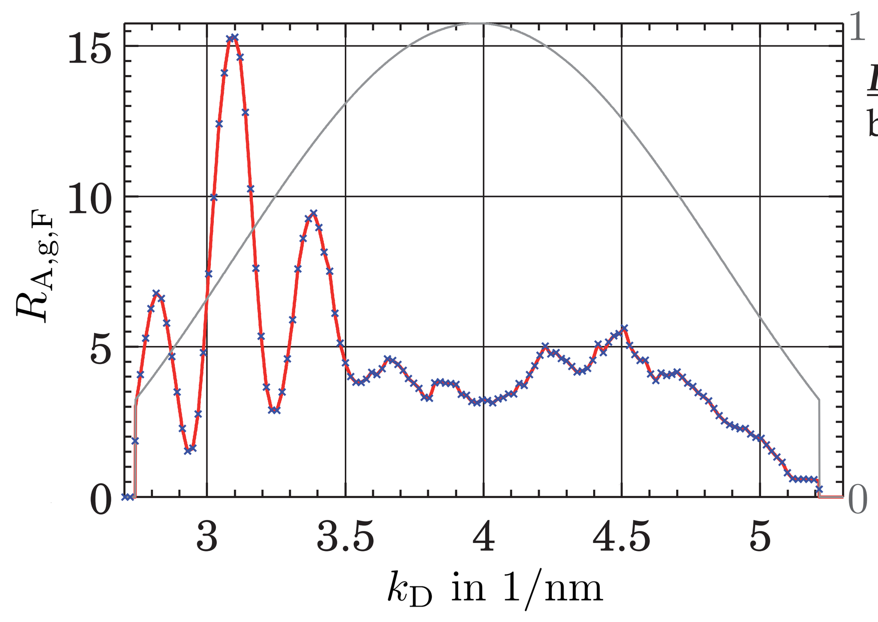
Raw data: spectral intensity between 30 and 100 eV depending on the dispersion-corrected wave number

Fourier-transform

Reconstructed depth structure: Fourier-transform of the spectral intensity



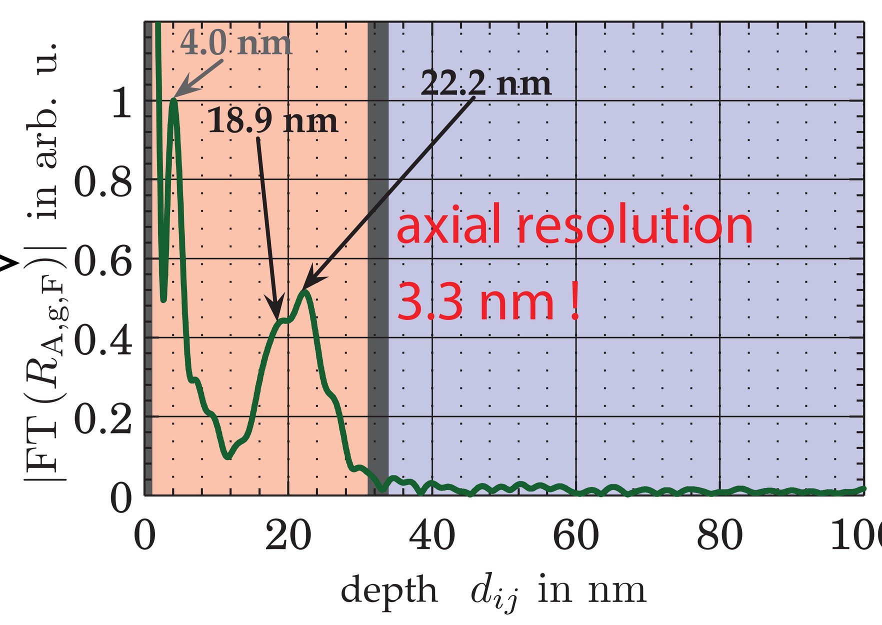
B_4C- & Pt-layers in the water-window



Raw data: spectral intensity between 280 and 560 eV

Fourier-transform

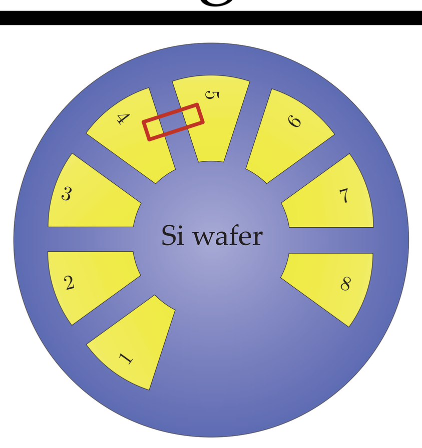
Reconstructed depth structure: with 3.3 nm axial resolution

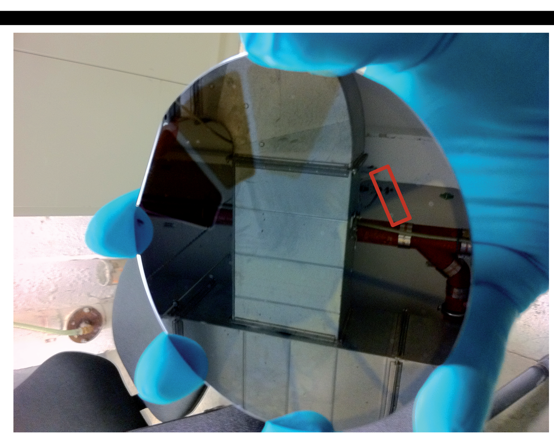


3D imaging by lateral scanning

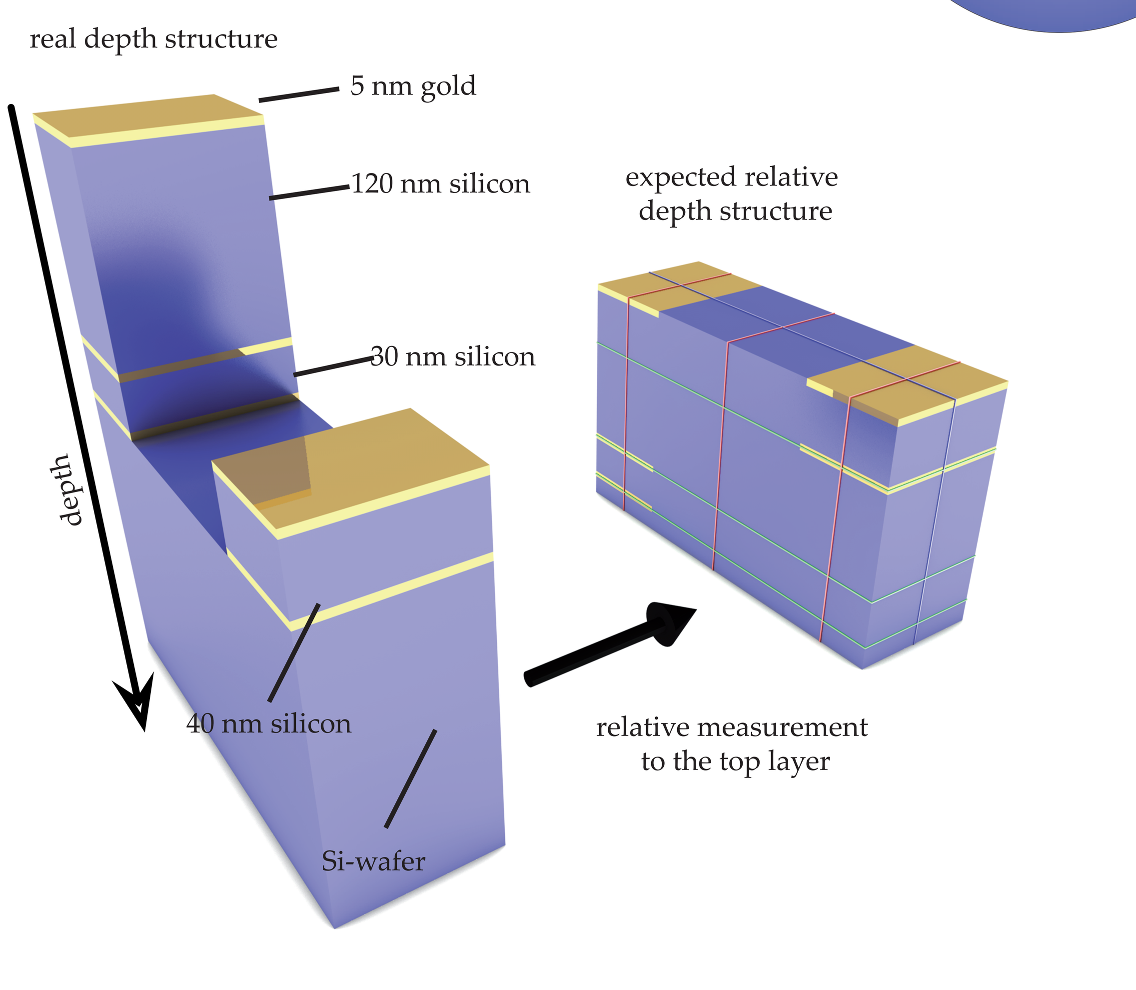
Sample design on Si-wafer

- different layer systems on a Si-wafer
- a volume consisting of different layer systems was imaged by a 3D scan





Schematic sketch of the imaged volume



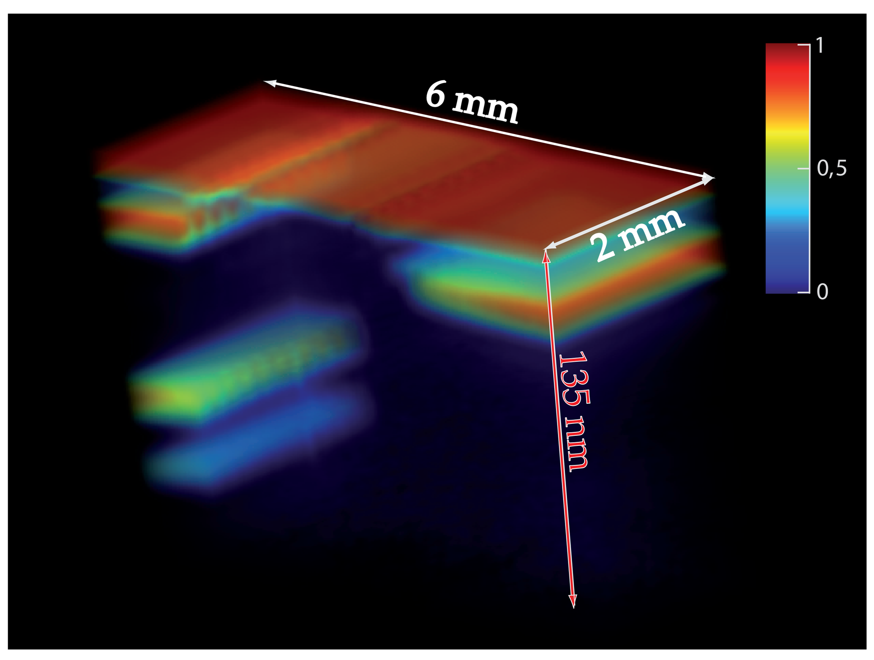
Result of the 3D scan

resolution: 12 nm (axial), 200 x 300 µm (lateral, because of the focus size)

stepwidth: 100 µm

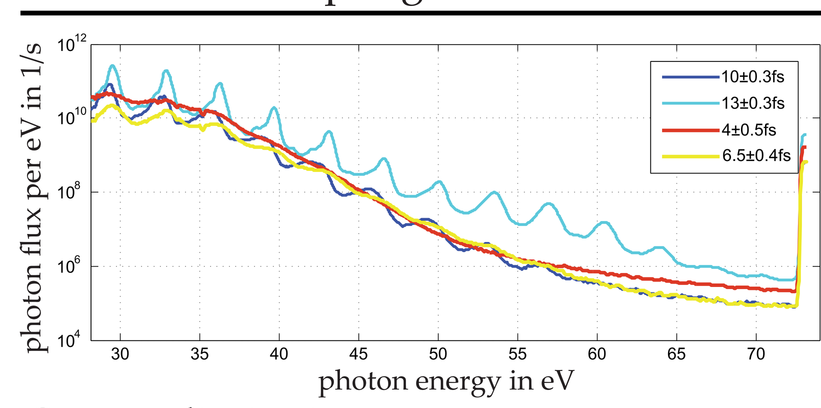
points of measurement: 1260

duration of measurement: 2.5 h



Towards XCT with laser-based sources

First results adapting a HHG source for XCT



- HHG with a few-cycle laser system in Argon
- pulse durations below 4 fs lead to isolated attosecond pulses and thus a smooth spectrum which is necessary for XCT

Current limitations

- photon flux 3 orders below synchrotron radiation (10^{11} photons/s)
- small bandwidth of 35 eV would reduce the axial resolution of XCT to 40 nm

Road map for further developments

- improving the photon flux by using lasers with higher pulse energy
- using longer wavelengths (>1000 nm) to increase the Cut-Off (~$I\lambda^2$) of the harmonic radiation and therefore the effective bandwidth for XCT

References:

[1] Huang et al.: Optical coherence tomography, Science, 1991

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[4] Henke, Gullikson, Davis.: X-ray interactions: Photoabsorption, Scattering, Transmission, and Reflection at E=50-30000 eV, Z=1-92, Atomic Data and Nuclear Data Tables, 1993

[5] Morlens et al.: Study of XUV beam splitter flatness for use on a Michelson interferometer, Laser und Particle Beams. 2004

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[8] Fuchs et al., Sensitivity calibration of an imaging extreme ultraviolet spectrometer-detector system for determining the efficiency of broadband extreme ultraviolet sources, Rev. Sci. Instrum, 2013

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